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# Application of a Buffer Layer for the Dielectric Measurement of Thin Polymer Films

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## ABSTRACT

A buffered dielectric measurement method is described. We added a thin buffer polymer layer to a polymer film before depositing aluminum electrodes. This is a modification to conventional parallel plate dielectric constant measurement method. It still has well-defined geometric factor for determining the dielectric constant. We designed the buffer layer using a simple RC model. It was determined that the buffer layer should be a high dielectric constant polymer. Two high dielectric constant polymers were selected to be buffer layers. Layered samples with structures ABA and ABC were discussed, where A is the buffer layer. We show that the method not only provides a way to preserve the structure of special polymer films, but also is able to adjust its electrical characterization to a convenient level.

## INTRODUCTION

The dielectric electrical characterization for thin polymer films is not only of fundamental interest, but also is critically important to their electronic application. To have a well-defined geometric factor, conventional dielectric constant measurement technique uses the parallel plate method. It is often performed depositing a metal electrode onto the thin film directly. This MPM (metal-polymer-metal) structure is simple, direct and reliable. However, increasingly, the direct metal deposition method is undesirable due to decreasing film thickness, or in studying of materials such as biopolymers. We have attempted to develop a buffer layer method by adding an additional layer on the top of the thin-film. The method is not only for the protection of ultra thin film, but also for adjustment of the electrical characterization of the sample to a frequency range that is convenient for specific instrument level.

The studies of dielectric data of the layered materials are available in literature. [1] However, we approached the problem from methodology point of view. In this paper, we presented a preliminary attempt to use buffer layer to create layered samples. We first analyzed the electrical requirement for the buffer layer. We illustrate the discussion with structures of ABA and ABC, where A is the selected buffering layer polymer. One of the sample films was down to nano-meter range.

## EXPERIMENTAL

Polymer thin films used in this experimental are assumed to be typical samples with typical dielectric constants as discussed. Polyvinylidenedifloride (PVDF) and cyanoresin (CRS) were used as buffer layer materials. Dielectric constant of PVDF and CRS are 12 and 20, respectively. Aluminum electrodes were vacuum deposited on the top of the buffer layer.

Dielectric measurements were performed with Hewlett-Packard 4194A Analyzer for the frequency from 100 Hz to $10^7$ Hz, and with Gamry Instrument from 5000 Hz to 0.001 Hz. All measurements were done at ambient temperature. The data from the frequency-overlapping region of the two instruments were usually in good agreement. They were used to indicate the quality of the data set and in estimating data uncertainty. The combined standard uncertainties of these data were estimated to be at the level of 10 % of the measured values. [2,3]

## RESULTS AND DISCUSSION

### Serial RC Model

Figure 1 shows a simple serial RC model for analyzing impedance data. This circuit is sufficient for our two-component application. In this model, each RC represents one thin-film material. We also expect each impedance arc from the materials is a half circle.

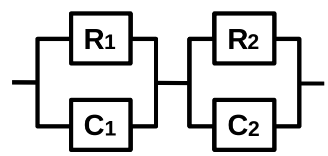



Figure 1. Serial RC model

Figure 2 illustrates that two materials need to yield

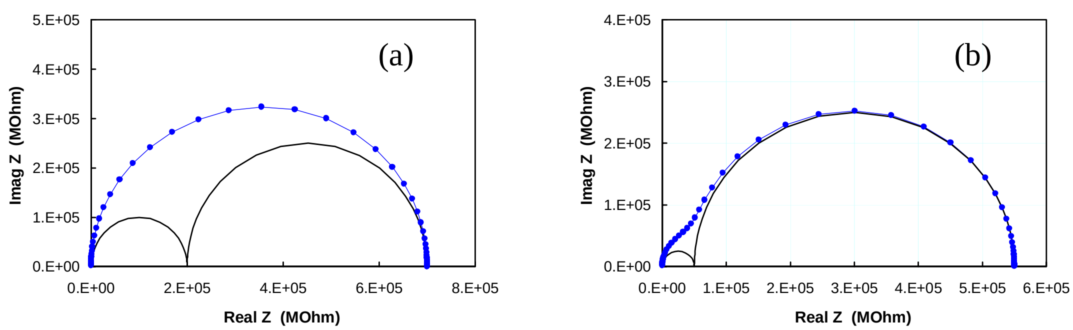
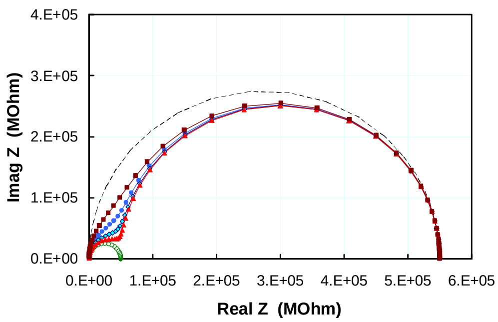



Figure 2. Impedance spectra model of two-layer films. (a) Similar films, (b) very different films.

visually separable two arcs. If the values of two RC's are similar, the resulted arc will look like Figure 2a. Since many materials have an impedance data already like Figure 2a, it is difficult to tell the difference where the $1^{st}$ film ends and where the $2^{nd}$ film starts. We would like to have an impedance data like Figure 2b, that two arcs are separable. The difference in resistance, R in Figure 2b is about 10. In such case, conducting polymers could be used. We also notice that the two arcs are really not well separated at the region where two arcs joined. To achieve the separation, we must change the dielectric constant of the buffer layer.

## Design a Buffer Layer

To design a buffer layers we changed the dielectric properties the sample. Figure 3 illustrates effect of impedances with increasing dielectric constant of the buffer layer. As the dielectric constant of the buffer RC increases the dip between two arcs increases. Curves 1 and 6 are



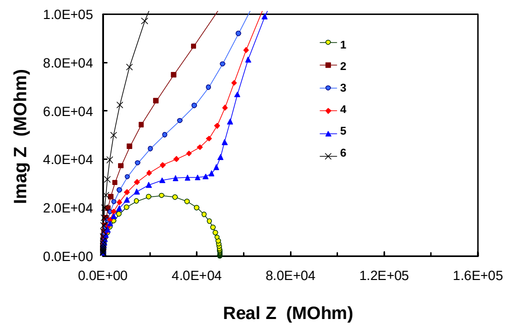




Figure 3. Calculated impedances of materials with different capacitance values.

single RC arcs. From curve 2 to 5, we doubled the capacitance for each RC circuit. Figure 3 indicates that we need about one order increase in dielectric constant in order to see the effect of arc separation. Hence, we concluded that the buffer layer is best served using a high dielectric polymer.

## Thin-Films with Buffer Layers

Figures 4-6 shows Cole-Cole plot of the complex dielectric constants of layered polymer films. These data were intended for illustration of the method of applying the buffer layers. The detailed properties of the polymer layer are not the subject of this work.

Figure 4 shows the complex dielectric constants of a three-layer ABA polymer film. The arc, the maximum near 20 Hz, was from buffer layer A, which were PVDF films. Clearly, one can separate the contribution from two components. One should use the arc span to determine the dielectric constant of each component.

Figure 5 shows the complex dielectric constants of non-symmetric layered polymer films. We spin-coated a layer of CRS polymer on the surface of a 700 nm polymer film, which already had been deposited on a silicon wafer. The three layers structure was non-symmetric ABC form. Now we have three arcs due to three different characteristic relaxation times. Since the film was thinner, the capacitances were also larger. We are also able to separate the contributions from all three components clearly.

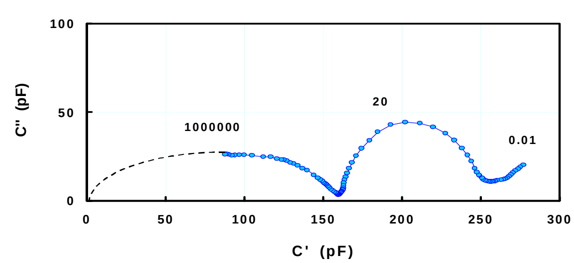



Figure 4. Complex dielectric constants of a three-layer polymer film.

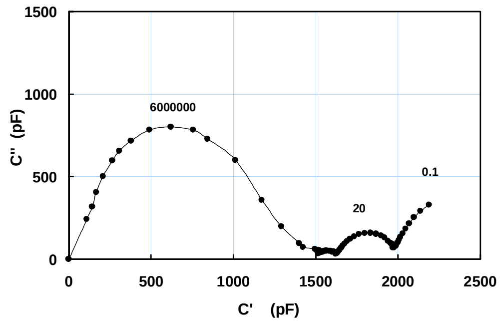



Figure 5. Complex dielectric constants of non-symmetric layered film.

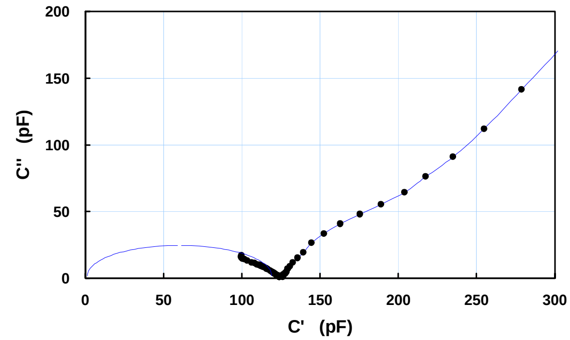



Figure 6. Complex dielectric constants of a buffered 250nm polymer film

Figure 6 shows the complex dielectric constants of 250 nm thin film between two CRS buffer layers. Here we observed only one clear minimum. The CRS arc does not show a clear minimum. However, this data still provide us relative clear picture on properties of the nano-scale thin polymer if that is what we are interested in.

The three sets of films, with different film thickness from micrometers down to the order of nanometer range, behaved as predicted from simple circuit model. This indicated that the high dielectric constant buffer layer effectively served as buffer layer for ac electrical measurement.

## CONCLUSIONS

We have developed a buffer method and the buffer polymer materials for the study of the dielectric properties of polymer thin-films. The method should be useful when the preservation of polymer film is required, such as ultra-thin films and biological films. The method also provides a way to adjust the electrical characterization of the materials to the frequency range where measurement instrument is most effective. Our results suggested the use of high dielectric buffer polymers yields clearly separated RC arc, which makes the data interpretation easier for typical polymer films.

## REFERENCES

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2. R. Popielarz, C. K. Chiang, R. Nozaki, J. Obrzut. Mater. Res. Soc. Symp. Proc. Organic/Inorganic Hybrid Materials, 628, CC11-5, (2001).
3. Certain instruments and materials identified in this paper are to adequately specify experimental details. In no case does it imply endorsement by NIST or that those are necessarily the best for the purposes specified.